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(54) High Pressure Abrasive-Fluid Jet Mixing and Accelerating Nozzle for Cutting and Drilling Hard Material

(72) Ismail, Mamdouh G.,
Canada

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ABSTRACT

This invention disclosure describes a new hard material cutting and drilling tool and cutting system method. This technique, a high energy abrasive-fluid jet, cuts by accelerating abrasive particles with high velocity eroding fluid jet stream(s). The concept of using fluid-accelerated abrasive particles for material removal has been demonstrated with both wet sand-blasting techniques and gas powered abrasive jet systems. In these methods, no deep penetration can be achieved. Abrasive-fluid jet cutting is an extension to these technologies which produce deep cuts in high strength advanced composites for a wide range of applications. The success of this new technique is achieved by reducing nozzle wear, producing a coherent stream and maximizing the abrasive particle exit velocity. The advantages of this new technique include versatility in cutting a wide range of material with deep kerfing capability with no fire hazards, low power levels needed, high edge quality, no delamination, no spallin, no thermal distortion, low noise, adaptability to remote operations, contour cutting and availability of the element used. The potentials for this technique include oil well casing perforation and drilling, use as an augmenting tool, cutting under water, steel platforms for off shore drilling, cutting steel pipe-lines, rock, concrete, glass, metal honeycomb, foams, laminated metal, etc., bore hole mining applications and forming a bottle shape hole by jet drilling.

BACKGROUND OF THE INVENTION

The purpose of this invention is to cut and drill hard material by abrasive-fluid jet mixing and accelerating using a high velocity fluid jet nozzle driven by pressures up to 55,000 PSI. The high velocity fluid jet flow mixes concentrically in a chamber in which different types of abrasives are fed. The shape and size of that mixing chamber affect the mixing efficiency and the jet cutting capability. Proper selection of the ratio of the fluid jet orifice diameter to the exit jet diameter is essential for an efficient cutting and abrasives suction.

The abrasives flow passage should uniformly change without sharp turns or sudden reduction in area. As high velocity fluid jets are turbulent with very high Reynolds numbers; mixing is expected to occur over a short distance from the fluid orifice exit.

The secondary mixing exit cone acts to prevent the spread associated with the jet flows. This mixing cone should be wear resistant, especially for tangential flow.

The entry angle of the abrasives downstream of the fluid jet is important for good mixing despite the great difference in momentum between the two phases of the jet. The principal of cutting is believed to be due to the super position of the fluid phase pressure on the abrasive particle impact. An efficient jet should not have a third gas phase. This is achieved by minimizing air suction.

Two basic types of commercial sandblasting or AJM nozzles can be distinguished. They are the venturi type nozzles and the straight bore nozzles. In these types the ratio K/S does not exceed 20 and is much less for small diameters in the range of 0.09 to 0.13 inches. These nozzles when used as mixing sections for abrasive fluid jet cutting experience rapid wear associated with decaying performance characteristics due to their unfavorable geometric configuration.

For example, a reduction of 55% in depth of cut in mild steel was observed when the nozzle wore out to 143%

of its original diameter. This wear rate was observed to slow down when longer mixing nozzles were used instead of the commercial nozzles. An improvement of 300% to 380% in service life was observed when (K) was doubled.

The parameters that influence optimum nozzle design criteria and nozzle geometry defined by its straight bar lenght (K) and diameter (S) are:

the abrasive particle size (g)
the abrasive flow rate (δ_r)
the fluid jet orifice size (B)
the fluid jet driving pressure (P)

For example, the use of some abrasives with particle size (g) will immediately constrain the choice of minimum mixing nozzle diameter (S).

In addition, high fluid jet pressures may require longer nozzles for maximum possible momentum transfer to the abrasives in the controlled nozzle environment. The optimum ratio (K/S) should then be a function of all these parameters.

Simplified mixing analysis can yield approximate relationships in support of the previous argument. However, very complicated theory will be required for an accurate relationship among these parameters.

The success of the abrasive-fluid jet cutting and drilling nozzle relies on the satisfactory performance to reduce nozzle wear, to produce a coherent stream and to maximize the abrasive particle exit velocity. The achievement of the above criteria requires the availability of a material for nozzle manufacturing such as baron carbid, silicon carbid, tungsten carbid and alumina ceramics.

The use of optimum nozzle geometric configuration will result in the use of inexpensive materials in simple forms. Explicit gains related to the optimized nozzle include the improvement of cutting rates and quality, the reduction in nozzle replacement costs and the cost reduction of hydraulic power.

Brief Description of the Drawings

The following drawings illustrate embodiments of the invention:

Fig. 1 Venturi type nozzles and the straight bore nozzles

Fig. 2 Nozzle friction loss zone and acceleration zone

Fig. 3 Nozzle design showing length of entry zone K_0, length K_1, length K_2 not to exceed the accelerating length

Fig. 4 Single jet multiple abrasive feed front view main section

Fig. 5 Single jet multiple abrasive feed top view main section

Fig. 6 Alternative design

Fig. 7 Abrasive-fluid jet cutting system

Detailed Description of Nozzle (Y) Assembly

The nozzle (Y) in figures (4) and (6) consist primarily of three (3) major components:

1- high pressure tube with an exit fluid jet orifice

2- a mixing chamber

3- nozzle exit outlet

The high pressure fluid jet is formed through a jet orifice to guarantee a high quality jet and a long life. The exit cone is made of a wear resistant material special for tangential abrasive flows. The adapter body shown in Figure (4) is used to produce a gradual change in abrasives flow area and minimize the size of the exit cone.

The seal material is required for efficient suction. This controls the abrasives flow rate and allows changes in the velocity of approach. The jet orifice holder can be reached by simply unscrewing it after removing the high pressure tube. The whole external body can be removed to check wear of the protective parts.

The design shown in Figure (4) allows the abrasives to enter the mixing chamber from three (3) entry holes. This may be useful when feeding three (3) different abrasives or more, either simultaneously or separately. This is required while cutting concrete with steel rebars.

B

Concrete requires large size abrasives while steel rebars require small sizes. Another advantage of multiple feed is the uniformity of mixing.

An alternative design is shown in Figure (6) which attempt to reduce the distance (V) and minimize the volume of the secondary nozzle. This will be more effective and also reduce exit nozzle replacement costs.

Nozzle Geometry

The nozzle geometry related to this invention is similar to the straight bore type nozzle in Figure (1) with proper relation between the length (K) and the diameter (S). To illustrate the concept behind the proper choice of these parameters the length (K) can be divided into three (3) regions as shown in Figure (2).

These regions are:

region (1) - in this region, the abrasives are reoriented to assume a predominantly axial velocity vector rather than the random orientations at which the abrasives are introduced. At the end of this region, the abrasive particle velocity is slower than the surrounding fluid velocity, that is:

$$V_f > V_a$$

region (2) - in this region, the abrasives are accelerated by momentum transfer from the surrounding fluid. The maximum possible velocity the abrasives can attain is that of the surrounding fluid, this means $V_a \cong V_f$

region (3) - in this region, friction losses will contribute to abrasives deceleration, so this region should be avoided in the design.

Design Analysis Recommendation

1- the two (2) regions (K_1) and (K_2) should be made of hard material to withstand random angle abrasive particle impacts or be made thick enough such that erosion will self machine the inside contour.

2- the top entry region is not critical as long as no

obstructions to the abrasive flow exists. The length of this section should not allow excessive jet spreading before entry to the straight bore and should not be less than a few particle diameters.

3- the rest of the nozzle length should not exceed the accelerating length. The nozzle thickness in this region can be less than that of Region (1). Also cheaper wear resistant materials can be used. The nozzle design can then be made of two (2) separate sections as shown in Figure (3).

4- for efficient momentum transfer, the fluid jet diameter, the particle size and the nozzle diameter should be close in dimension so as to satisfy the two conditions

$$S > B$$
$$S > g$$

But the relation between B and g can be $B \gtrless g$

5- the abrasives are prefered to enter the top of the nozzle with minimum turbulence and with as "axial" a velocity vector as possible. This will accelerate the reorientation process with reduced wear rates in region (1). However, the length of the second region remains the most influential in terms of cutting performance.

6- the second region (K_2) can be a simple straight bore cylinder easy to manufacture and replace with minimum downtime cost.

<u>Abrasive-fluid Jet Cutting Process Description</u>

The high velocity fluid (up to 3000 ft/sec) flowing in the mixing chamber, as shown in the nozzle assembly design of Figure (4), causes vacuum which draws abrasives from an abrasive storage source. The hose connecting the nozzle assembly to the abrasive source is flexible and can be up to 200 ft long with an I.D. of 0.5 inch. The fluid jet is produced using high pressure (up to 60,000 PSI) developed by a positive displacement pump (intensifier). The jet is formed through a jet orifice of openings ranging between 0.003 to 0.05 inch diameter.

B

In the drawings, the numbers correspond to:

1: k
2: S
3: K
4: venturi type nozzles
5: straight bore type nozzle
6: section (2)
7: section (3)
8: friction loss zone K_3
9: $V_b > V_a$
10: V_b
11: V_a
12: $V_b = V_a$
13: V_b
14: V_a
15: *section* (1)
16: entry zone
17: reorientation zone K_1
18: reorientation zone (K_1), acceleration zone (K_2), friction loss zone (K_3)
19: acceleration zone (K_2)
20: fluid jet
21: length of entry zone K_0
22: length K_1
23: length K_2
24: distance of 2.50 cm
25: " 6.75 cm
26: " 1.00 cm
27: " 0.90 cm
28: " 16.20 cm
29: " 3.70 cm, hight of the bottom body part
30: " 10.00 cm, hight of upper body part
31: " 6.90 cm
32: " 2.20 cm
33: " 2.30 cm
34: " 2.30 cm
35: " 0.55 cm
36: " 0.80 cm
37: " 0.35 cm. This is the maximum hight of fluid jet orifice

B

38: security protective rubber
39: distance of 0.40 cm
40: " 2.55 cm screw (3)
41: seal
42: distance of 1.15 cm inside diameter of the mixing chamber
43: " 0.50 cm
44: " 4.50 cm
45: " 3.30 cm
46: fluid entry high pressure tube
47: abrasives
48: 53^o angles
49: distance of 1.00 cm out diameter of the abrasive hose
50: distance of 1.50 cm width of the protective plate
51: " 1.00 cm
52: " 3.20 cm
53: " 1.50 cm of screw head
54: " 2.30 cm
55: " 0.20 (min) to 0.25 (max) cm of the Tungsten carbide tube
56: distance of 0.50 cm
57: " 7.50 cm
58: circle diameter of 7.50 cm
59: circle diameter of 1.00 cm
60: diameter of high pressure tube 1.25 cm
61: screw (6) holding the protective rubber
62: seal
63: seal
64: distance of 2.90 cm
65: " 4.00 cm
66: " 1.50 cm width of the protective plate
67: abrasives supply source
68: abrasives filter
69: power unit
70: intensifier units
71: liquid supply source
72: nozzle assembly
73: liquid kerfing out of the nozzle assembly
74: depth of that supersonic active kerfing approximately one meter deep in hard material.

The foregoing description of my invention is not to be interpreted as limiting to the preferred embodiment described and illustrated herein, but applicant is considered entitled to any other embodiment of the nozzle assembly and apparatus as a whole which falls within the scope of his invention.

CLAIMS

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1- An abrasive fluid cutting apparatus connected to a source of highly pressurized fluid comprising: a generally cylindrical nozzle assembly consisting of two main parts one and two: part one including a high pressure tube with an exit fluid jet orifice, a mixing chamber having a plurality of inlets at one end thereof, one of said inlets being connected at said one end to said source of high pressure fluid; the other of said plurality of inlets being equally spaced around said first inlet and connected to said nozzle mixing chamber and to a source of abrasive particles, and into said mixing chamber ending into a converging entry zone, in said part two followed by a reorientation zone (K_1) and acceleration zone (K_2) said nozzle assembly further comprising two narrow discharge passages, said first of said two passages having an orifice located at one end thereof adjacent the mixing chamber, a transition zone diverging from said orifice into said mixing chamber, the other of said two narrow passages leading from said converging entry zone through said reorientation and acceleration zones, said fluid flow having a supersonic velocity fluid jet (with respect to air) at said orifice entering said mixing chamber creating a vacuum thereby causing the suction of said abrasive particles and mixing said particles with said fluid jet in said mixing chamber, said mixture subsequently reaching said converging entry zone, reorientation zone and acceleration zone;

2- Apparatus as defined in claim 1 wherein parameters influencing optimum mixing nozzles, assembly design criteria and nozzle assembly geometry defined by its straight bore length (K) and diameter (S) of said two narrow passages with $\frac{\text{length (K)}}{\text{diameter (S)}}$ values greater than 27;

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3- Apparatus as defined in claim 1 further comprising a first inlet which includes a fluid supply conduit communicating between said fluid inlet to a pressurized fluid source created by one or more positive displacement pumps (intensifier) activated by a power unit and regulated by valves;

4- Apparatus as defined in claims 1 and 3 wherein the other of said inlets further includes one or more abrasive conduits communicating at one end thereof to said abrasive inlet and at the other end thereof to said abrasive supply source;

5- Apparatus as defined in claim 3 wherein said abrasive supply source further includes a first air inlet opening into in an abrasive conduit adjacent said abrasive source and a second inlet opening in said abrasive conduit spaced from said abrasive source, whereby said abrasive source and external atmosphere communicate by operating an adjustable valve connected into a second air inlet opening for regulating the flow of air and filtering the abrasive therethrough;

6- A process for use with apparatus of claim 5 comprises the step of selectively controlling the rate of feed of said flow particles into said fluid jet and the selection of the types of abrasives fed, in response to the thickness of the material, the degree of hardness and difficulty of cutting the workpiece;

7- Apparatus defined in claim 1 wherein said mixing chamber is further caracterised by a frustoconical inner section and a cylindrical outer section, said inner section being connected to said mixing chamber at the larger end thereof and having a junction with said cylindrical section at the smaller end thereof, both inner and outer sections having the same longitudinal axis; the said conical shaped section receiving the fluid mixed with the abrasive particles coming from the mixing chamber accelerated to high velocity by the fluid jet; the said straight bore cylinder receiving abrasive particles maximizing momentum transfer from the fluid to the abrasive particles in the controlled nozzle environment;

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8- Apparatus defined in claim 7 wherein said passageway frustoconical section further includes an orifice to lead high pressure fluid toward said conical section, the use of mixing diameters ranging between 1.25 fluid jet orifice diameter to 15 orifice diameter producing thereby a high velocity fluid jet and creating the vacuum inside the mixing chamber allowing the suction of abrasive particles and efficient cutting;

9- Apparatus defined in claim 8 further including an orifice on the side wall of said frustoconical section leading to abrasive supplying source;

10- Apparatus defined in claim 7 further comprising a cylindrical outer section connected to the mixing chamber and to end of nozzle assembly; having entry zone converging in conical shape, reorientation zone K_1 and acceleration zone (K_2) in the form of a long straight bore passage with lengths ranging between 1.00 to 15.00 inches long with a diameter between 0.008 to 0.30 inches;

11- Apparatus defined in claim 1 further comprising the use of passages and proper particle diameters, ranging between 2½ and 15 particle diameters, further including selectively controlling the rate of feed of said flow particles into said fluid jet and the use of an orifice to provice a gradual diverging inlet fluid jet of conical shape or solid blade, in order to obtain the best cutting performance for a wide range of materials;

12- The process in accordance with claim 6 further caracterised by the step of introducing a fluid with a supersonic velocity through an orifice into a nozzle's frustoconical section to produce a gradually diverging conical fluid jet in said section to create a vacuum causing the drawing of abrasive particles mixing it with the entering fluid supersonic jet in the mixing chamber, the whole being propelled toward the second narrow passage exit outlet, cutting any material on its way, the nozzle being also operated without abrasive.

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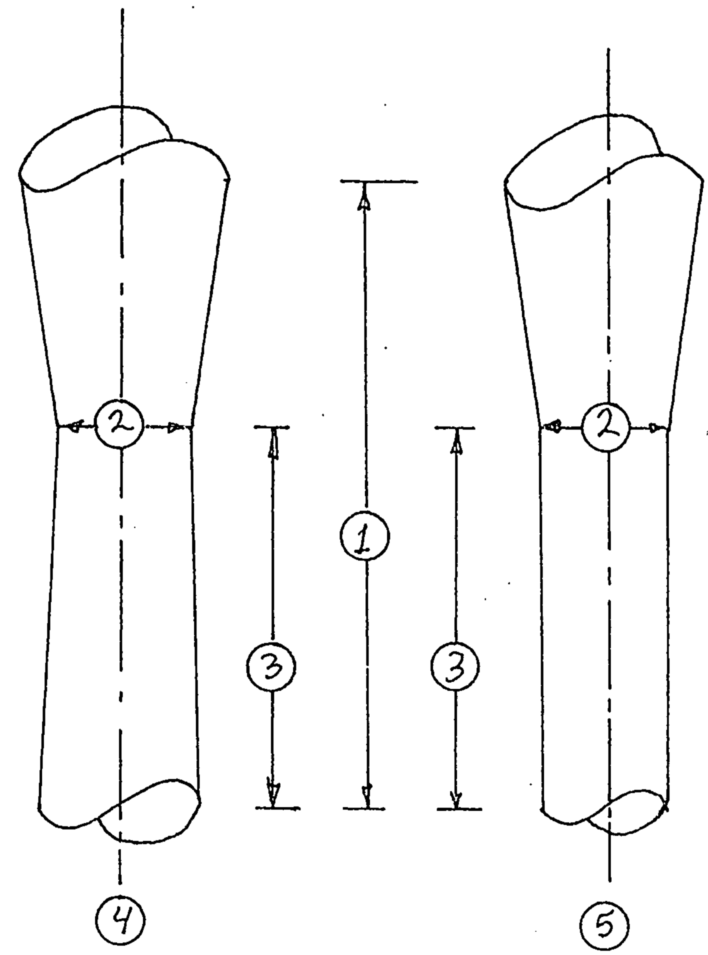

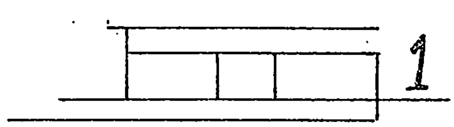

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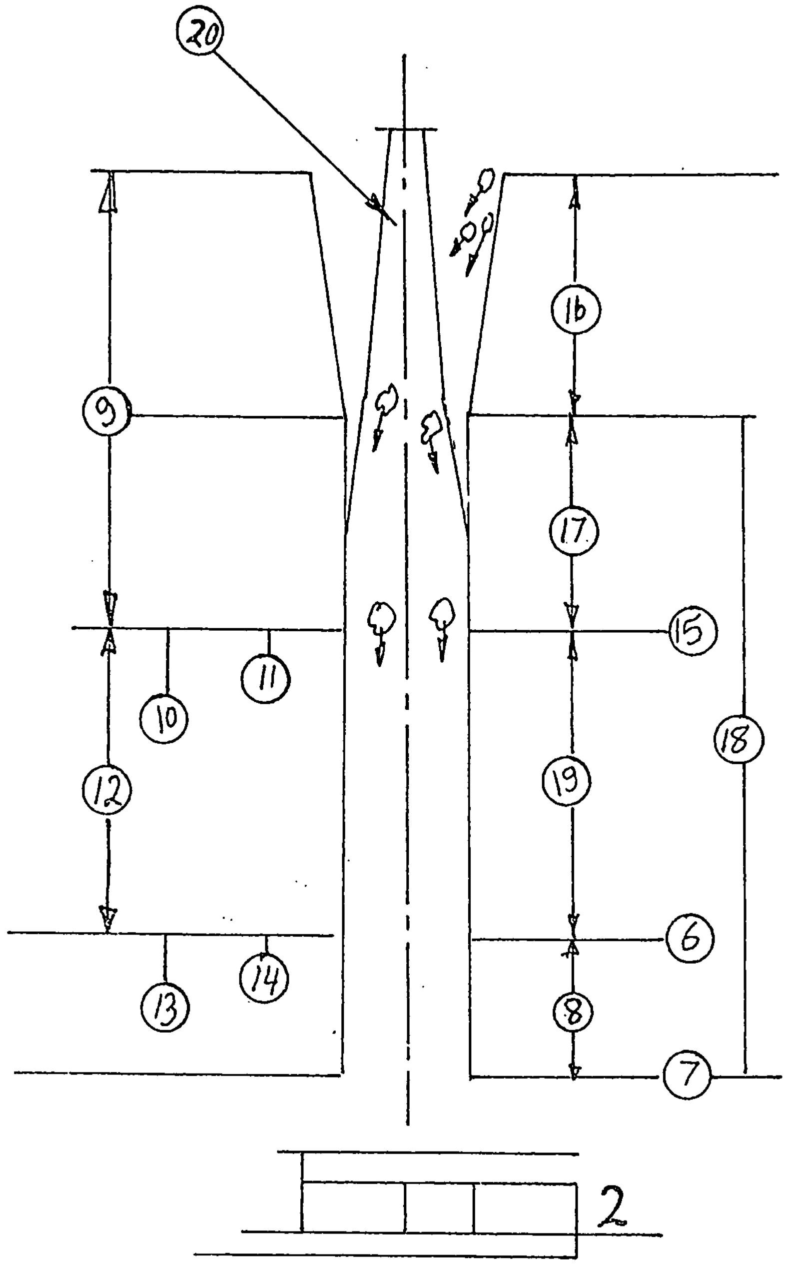

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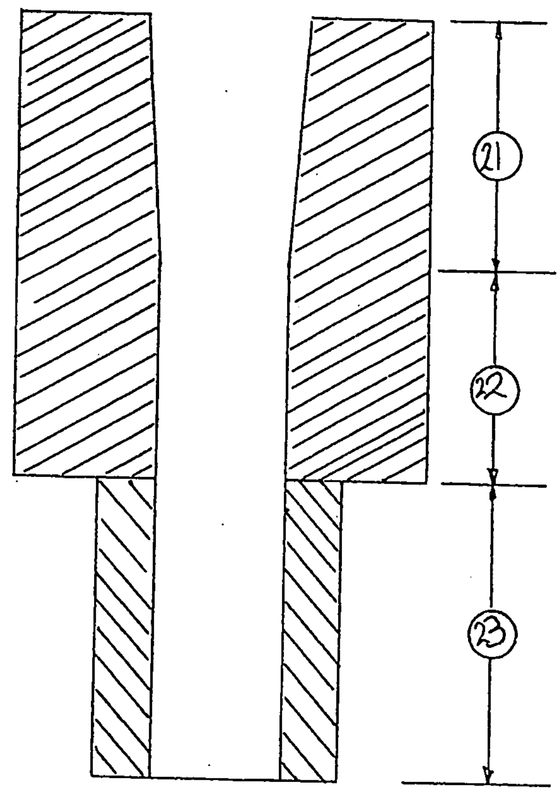

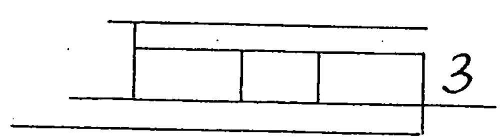

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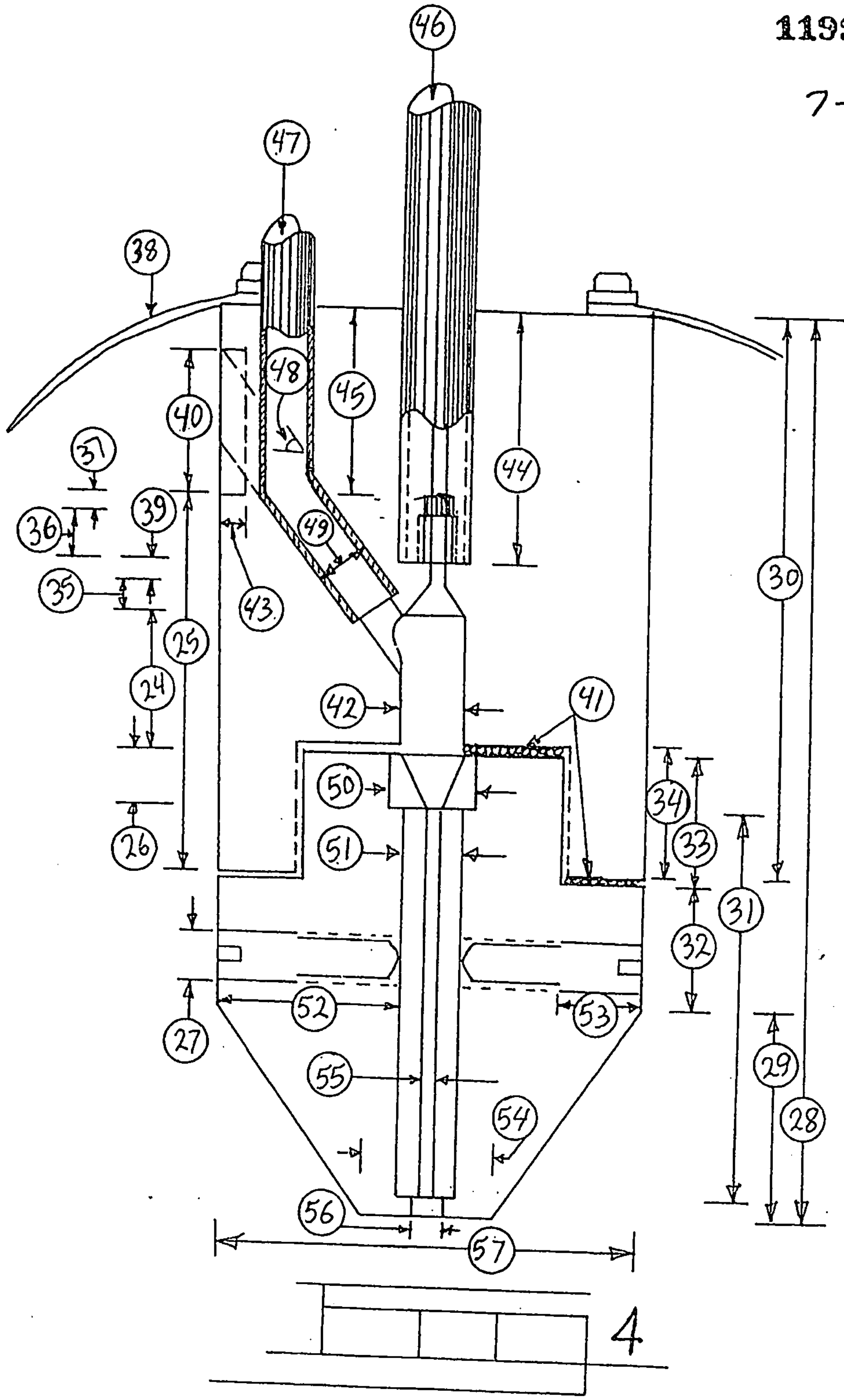

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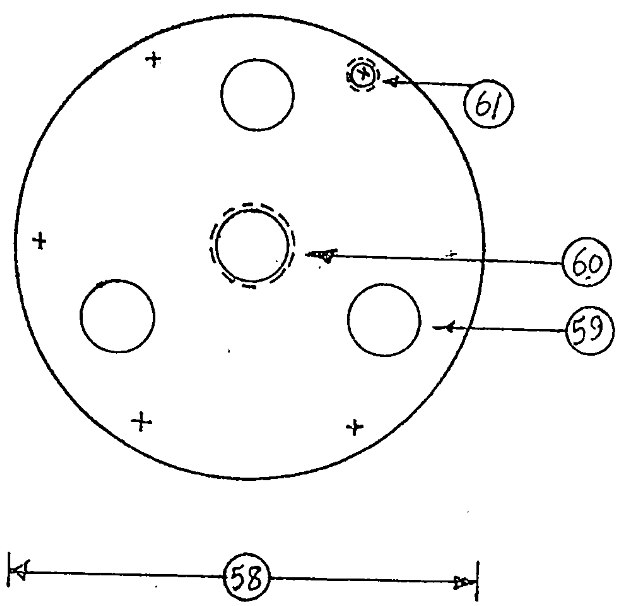

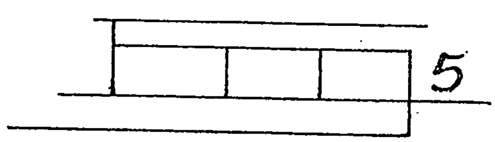

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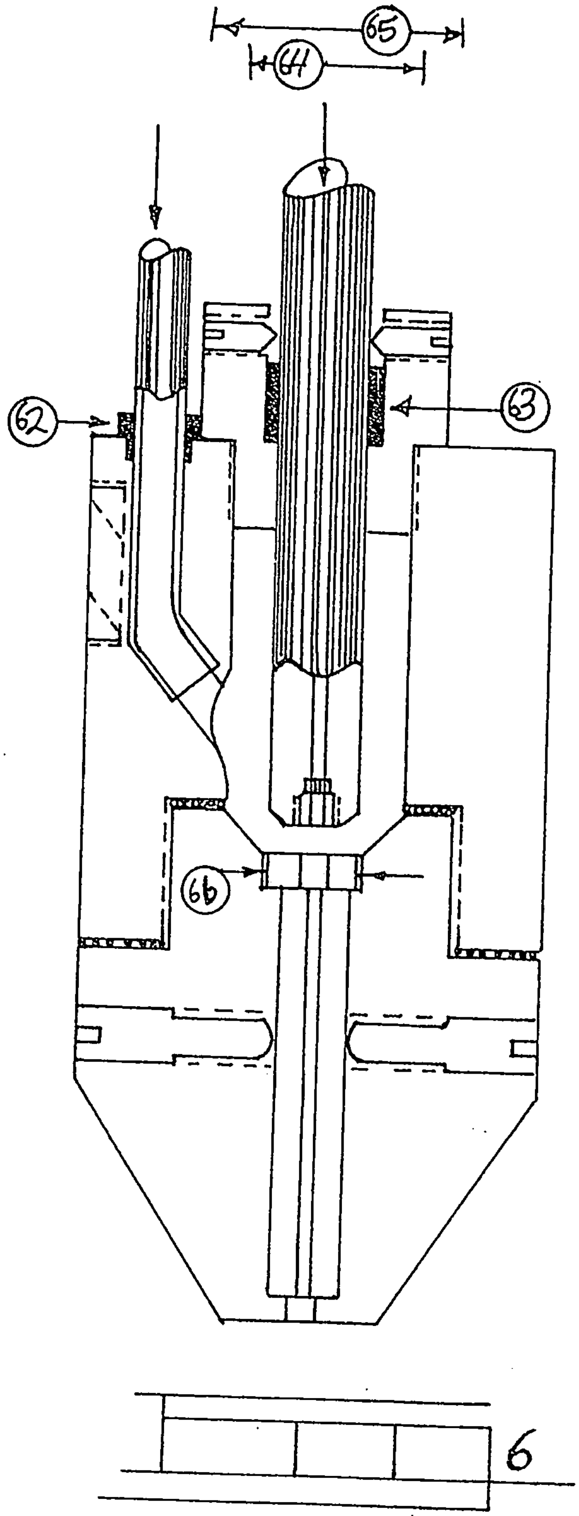

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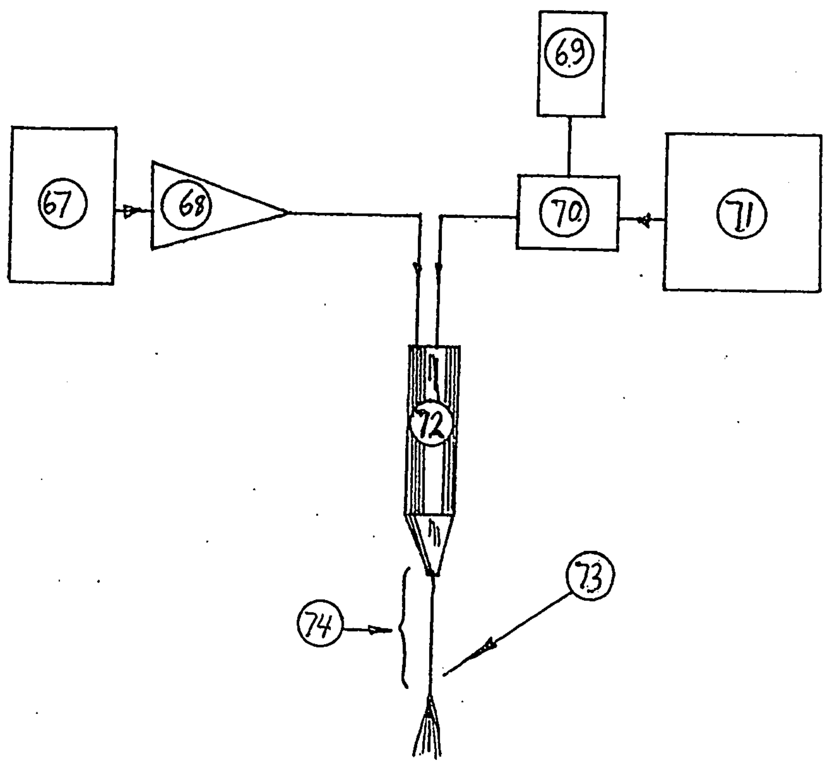

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